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Current Status of Simulation and Training Models in Urological Surgery: A Systematic Review

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ABSTRACT

Purpose: Increased awareness of patient safety, advances in surgical technology and reduced working times have led to the adoption of simulation-enhanced training. However, simulators available need to be scientifically evaluated before integration into curricula. The aim of this study is to identify the currently available training models for urological surgery, their status of validation and evidence behind each model.

Materials and Methods: Medline, EMBASE and Cochrane library databases were searched for English language articles published between 1990 and 2015, describing urological simulators and/or validation studies of these models. All studies were assessed for level of evidence and each model was subsequently awarded a level of recommendation, using a modified Oxford Centre for Evidence-Based Medicine classification, adapted for education by the European Association of Endoscopic Surgeons.

Results: A total of 91 validation studies were identified pertaining to training models in endourology (n=63), laparoscopic surgery (n=17), robot-assisted surgery (n=8) and open urological surgery (n=6), with a total of 55 models. Of the included studies, six were classified Level 1b, nine Level 2a, 39 Level 2b and 19 Level 2c. Amongst all the training models, the URO-Mentor was the only model to receive a Level of Recommendation of 1.

Conclusions: UroSimulation is a growing field and increasing numbers of models are being produced. However, there are still too few validation studies with high level of evidence demonstrating the transferability of skills. Nevertheless, efforts should be made to utilise the currently available models in curriculum-based training programmes.

INTRODUCTION

Surgery as a craft has traditionally been learnt via an apprenticeship scheme, in which the famous slogan, "see one, do one, teach one" was coined, describing how surgical skills were attained for many decades [1]. This method of training produced highly skilled surgeons for a number of generations. However, with increased awareness of patient safety, reduced working hours and financial constraints in healthcare organisations, this model has presented challenges for trainees to obtain the required level of competency [2].

Further challenges have risen with the development of minimally invasive techniques, largely associated with steeper learning curves. With growing realisation that a large part of the procedural learning curve does not require patients for skill acquisition, but can be learnt on training models, there has been a boom in the production of training models [3]. This increase has brought about the need to scientifically evaluate these models to establish their educational value and role in training. Thus, increasing number of validation studies are being conducted to investigate the usefulness of simulators.

The aim of this study is to identify the currently available training models for urological surgery and their status of validation. It also aims to evaluate the level of evidence (LoE) behind each training model and, thereby, establish a level of recommendation (LoR).

METHODS

This study was performed using the guidelines set out by the Preferred Reporting Items for Systematic reviews And meta-analysis (PRISMA) statement (Figure 1) [4].

Study Eligibility Criteria

Original research articles describing validation and use of urology training models and simulators were included in the review. Studies addressing basic surgical skills were excluded, as were those that only described the use of models without a validation process. Abstracts with insufficient information and non-English articles were also excluded.

Information Sources and Search

A broad search was performed on Medline, EMBASE and Cochrane library databases, between January 1990 and December 2015. Search terms included “simulation in urology” and “simulation training in urology”, which allowed for the majority of articles to be found. A further procedure-specific search was performed using “TURP”, “TURBT”, “Nephrectomy”, “HoLEP”, “PVP”, “PCNL”, “Laser”, “diode”, “GreenLight” and “robotic” followed by “simulation” or “training”, to supplement the identified studies.

Study Selection and Data Collection

After meeting the inclusion criteria, articles were retrieved in full and titles and abstracts were examined. Abstracts from conferences were also included, if sufficient information could be extracted. Duplicates were removed. Full-text review further excluded studies, which were not validation or educational impact studies. Potentially relevant articles found in the references of included articles were also retrieved and made subject to the inclusion/exclusion criteria.

Data Items

Selected data was extracted from each study including the name of model, institution/manufacturer, type of validation, number of participants and demographics. Models and simulators were classified into the following categories: bench, augmented reality (AR), virtual reality (VR), animal and cadaveric models. Results were tabulated and studies concerning each simulator were grouped together. The type of validities were classified according to the definitions of McDougall [5] and van Nortwick et al. [6] (Figure 2). LoE for each study and LoR for each model was awarded using a modified educational Oxford Centre for Evidence-Based Medicine (OCEBM) LoE and LoR classification system, as adapted by the European Association of Endoscopic Surgery [7] (Supplementary Tables).

RESULTS

In total, 5163 potentially relevant studies were identified. Upon review and examination of the full texts, 91 of the initially retrieved studies met the inclusion criteria (Figure 1). Results were categorised into endourology, laparoscopic urology, robot-assisted urological surgery and open urological surgery (Tables 1-5). In cases where studies failed to demonstrate the aimed validity, these were indicated with a strike through the text and where studies did not provide adequate information, these were hyphenated in the relevant sections of the tables. In instances where LoR could not be awarded, these were marked with not-applicable (N/A).

Endourology

Sixty-three studies were identified concerning training models for different endourological procedures, most of which were for ureterorenoscopy followed by urethrocystoscopy and transurethral resection, repectively.

Urethrocystoscopy

Eighteen articles were identified describing validated models utilised in flexible and rigid cystoscopy training (Table 1), with eleven using the URO Mentor VR simulator (Simbionix, Israel) alone. The URO Mentor has demonstrated face (n=4), content (n=2), construct A (n=6) and construct B validities (n=6) for urethrocystoscopy, and was awarded LoR of 1. This VR simulator was also evaluated when used in conjunction with a bench model. Gettman et al. [8] developed a standardised cystoscopy curriculum using the URO Mentor and showed significant improvements with additional simulator time amongst 10 novices. A complementary study [9] with 80 subjects demonstrated construct validity of the model; while a randomised controlled trial (RCT) [10] of 100 subjects demonstrated transfer of skills from the VR simulator to the operating room.

Fresh frozen cadavers (FFC) were utilised for rigid and flexible cystoscopy by two studies [11 12] and received a LoR of 2. Bowling et al. [11] demonstrated construct B validity amongst 29 obstetric residents whilst Ahmed et al. [12] described the British Association of Urological Surgeons (BAUS) Human Cadaver Training Programme and demonstrated face and content validity amongst 75 participants and 27 experts for a number of procedures including rigid and flexible cystoscopy, bladder biopsy and intravesical injection of botolinum toxin.

Ureterorenoscopy

Twenty-one studies were identified describing validated training models for ureterorenoscopy (Table 1), 11 of which described the URO Mentor once again. This VR simulator has demonstrated face (n=4), content (n=2), construct A (n=5), construct B (n=4), concurrent (n=1) and predictive validities (n=2) for ureterorenoscopy, and was awarded a LoR of 2.

Another more commonly used model is the Uro-Scopic Trainer (Limbs and Things, Bristol, UK). This bench model was evaluated by four studies and demonstrated face (n=1), construct A (n=3), construct B (n=1) and concurrent validities (n=1). The model received a LoR of 2. Two studies evaluated the combined use of these models [13 14] and demonstrated face and construct B validation, amongst 16 residents and 32 medical students, respectively.

Matsumoto et al. [15] also demonstrated Construct A validity of a low-fidelity model (cost: $20 CAN), consisting of a penrose drain, inverted cup, moulded latex and two straws, amongst 40 medical students. It, too, received a LoR of 2. This RCT compared the low fidelity model to the Uro-Scopic Trainer, a higher fidelity bench model (cost: $3700 CAN), and didactic lectures. Statistically significant improvements were seen in the two groups that had simulation training compared to a group that only received didactic lectures. However no differences were observed between the low and high fidelity group.

Several other bench models were also validated, including the Scope Trainer (Mediskills, Northampton, UK), Adult Ureteroscopy Trainer (Ideal Anatomic Modelling, Holt, Michigan, USA), Endo-Urologie Modell (Karl Storz GmbH, Tuttlingen, Germany) and Cook URS Model (Cook Medical, Bloomington, IN, USA), all of which received a LoR of 3.

Soria et al. [16] developed a three-stage curriculum whereby 40 participants were first taught theoretical knowledge and then utilised the ETXY-Uro Adam (ProDelphus, Olinda, Brazil) to perform urethrocystoscopy ,ureteral orifice cannulation and a semi-rigid ureteroscopy case. This was followed by laser lithotripsy and basket removal of stones on a porcine renoureteral unit. Finally, participants repeated task 1 on live porcine. The authors demonstrated face, content, construct A and construct B validity of their curriculum, receiving a LoE of 2b and LoR of 3.

Face and content validity of FFCs were demonstrated [12], but did not have sufficient LoE to receive a LoR.

Percutaneous renal surgery

Eight articles were identified for validated models utilised in the training of percutaneous renal surgery, describing a total of four training models (Table 1). The PERC Mentor (Simbionix, Israel) was evaluated by four studies and demonstrated face (n=2), content (n=2), construct A (n=2), construct B (n=2) and predictive validities (n=1). The simulator received a LoR of 2. Another study [17] used the PERC Mentor in conjunction with live porcine and demonstrated the content validity of both modalities.

The only identified bench model was the C-arm Trainer (SimPORTAL, University of Minnesota, MN, USA). The developers assessed and demonstrated the face and content validity of this new model. Two studies reported the use of porcine kidney for PCNL while. Zhang et al.[18] reported the face validity of using porcine kidneys amongst 42 urologists whilst Hammond et al.[19] placed the porcine kidney into a chicken carcass to represent the posterior tissue layers in humans and demonstrated face validity of this model amongst urology residents. All three models received a LoE of 4 and failed to receive a LoR.

Transurethral resection of the prostate (TURP)

Sixteen validation studies were identified for TURP training models (Table 2). Three training models equally received a LoR of 2. The Bristol TURP Trainer (Limbs and Things), SurgicalSIM TURP Trainer (METI, Seattle, WA, USA) and the UroSim TURP module (VirtaMed, Zurich, Switzerland) all demonstrated face, content and construct B validities. The PelvicVision VR Simulator (Melereit Medical AB, Linköping, Sweden) also demonstrated face, content and construct validity, but received a LoR of 3. Of these, the Bristol TURP Trainer is the only bench model, as opposed to the remaining VR simulators.

The TURP Simulator described and content validated by Ballaro et al. [20] was developed over a decade ago but has not been reported in the literature since or commercially available. The Uro Trainer (Karl Storz GmbH, Tutlingen, Germany) is also no longer commercially available and the name is, instead, used synonymously with custom-made UroSim, produced for Karl Storz.

Ahmed et al. [12] also described the TURP simulation with FFCs as part of the BAUS Human Cadaver Training Programme and demonstrated face and content validity.

Transurethral resection of bladder tumours (TURBT)

Three training models were identified for TURBT training (Table 2). The Uro Trainer VR simulator (Karl Storz GmbH) failed to demonstrate face and content validity in the study conducted by Schoutt et al. [21] whilst other studies demonstrated content (n=1), construct A (n=3) and construct B (n=1) validities of the simulator. However, as mentioned, this is no longer available and the TURBT module on the UroSim remains to be validated. Khan et al. [22] utilised the Bristol TURBT Trainer (Limbs and Things) and also demonstrated face, content and construct B validity. Similarly, the Simbla TURBT Simulator was also evaluated by de Vries et al. [23] and demonstrated face, content and construct B validity amongst 76 participants consisting of novices, intermediaries and experts. All three models received a LoR of 3.

Laser procedures of the prostate

A total of six studies were identified for models utilised in training for various laser prostate therapies (Table 2). These consisted of three VR simulators and one bench-top model. Two simulation models are available for Holmium laser enucleation of the prostate (HoLEP); the UroSim (VirtaMed) and HoLEP Simulator (Kansai Medical University, Japan). The former has demonstrated face, content and construct validity whilst the latter has only demonstrated face and content.

The GreenLight Simulator (American Medical Systems Inc., Minnetonka, MN, USA) is the only available simulator for GreenLight photoselective vaporisation of the prostate (PVP). Three studies evaluated this simulator and demonstrated face (n=2), content (n=1), construct A (n=2) and construct B validities (n=3). The MyoSim (VirtaMed) also demonstrated construct B validity by Angulo et al. [24] for diode laser PVP. The GreenLight Simulator was the only trainer to receive a LoR of 2, with the remaining scoring LoR of either ≤3 or N/A.

Laparoscopic Urology

Sixteen studies were identified describing validated models for three laparoscopic procedures (Table 3). The most commonly used modality was animal models.

Partial/Radical Nephrectomy

A total of eight studies described four different models for laparoscopic partial and/or radical nephrectomy. The Procedicus MIST Nephrectomy VR Simulator (Mentice, Gothenburg, Sweden) was the most thoroughly evaluated model, with two studies demonstrating its face, content and construct B validities. However, Wijn et al. [25] reported failure of the trainer to demonstrate construct validity in a cohort relatively higher in number. Nevertheless, this VR simulator received an overall LoR of 2. Similarly, the Partial

Nephrectomy dry-lab model (University of California, USA) also received a LoR of 2, with three studies demonstrating face (n=1), content (n=1) and construct B (n=2) validation.

Pyeloplasty

Four studies were identified for Laparoscopic Pyeloplasty, describing different bench (n=2) and animal (n=2) models, all of which received LoR of ≤3. Of note, Poniatowsky et al. [26] developed and validated a disposable, low-cost, high-fidelity, physical renal pelvis/ureter tissue analogue model for pyleoplasty training. The authors demonstrated face, content and construct validity amongst 31 participants. Jiang et al. [27] used a chicken crop and oesophagus model to simulate the human renal pelvis and ureter, respectively. This study demonstrated construct B validity of this model amongst 15 participants, where experienced participants outperformed intermediate and novices.

Ureteral Re-implantation

Tunitsky et al. [28] developed a dry-lab model for minimally invasive ureteral re-implantation from hydrogel. The authors demonstrated face, content and construct B validity amongst 20 subjects. The model received a LoR of ≤3.

Urethrovesical Anastomosis

Three studies were identified for urethro-vesical anastomosis models (UVA), all of which received LoR of ≤3. The RCT by Sabbagh et al. [29] evaluated a latex task-specific simulator for UVA and demonstrated its face and predictive validities. Anaesthetised pigs were used to assess performance, where the groups who trained on the model outperformed the control arm. The authors also demonstrated the face validity of the live porcine model. A number of other studies have also assessed the used of various animal models, including pig intestine and chicken models, and demonstrated construct B validity.

Robot-Assisted Urological Surgery

Eight studies were identified describing procedure-specific and validated training models for robot-assisted urological surgery (Table 4). The most commonly used robotic simulator was the da Vinci Skills Simulator (dVSS; Intuitive Surgical, Sunnyvale, CA, USA).

Robot-assisted partial nephrectomy (RAPN)

Three validation studies were identified for two RAPN models. Hung et al. [30] developed a partial nephrectomy model from porcine kidney and a Styrofoam ball, and established face, content and construct B validity amongst 46 participants, using the dVSS. Concurrent and predictive validities of the model were also established in a second study, amongst 24 participants. This model was awarded a LoR of 2. The same authors also developed a procedure-specific AR training platform on the dV-Trainer (Mimic Technologies, Seattle, WA, USA) for RAPN. The AR component includes surgical footage embedded with interactive exercises to teach relevant surgical anatomy, steps of the operation and advanced surgical skills such as tissue retraction, cutting and energy use. This is combined with a renorrhaphy VR exercise. The authors established face, content, construct B and concurrent validities. This platform received a LoR of 3.

Robot-assisted radical prostatectomy (RARP)

Three validation studies described two training models for UVA, an essential step in RARP, and received a LoR of 3. The Hands-on Surgical Training (HoST) is an AR system on the

Robotic Surgical Simulator (RoSS; Simulated Surgical Systems; Williamsville, NY, USA). Chowriappa et al. [31] performed a prospective RCT and demonstrated face and concurrent validities, amongst 52 participants. Although the study is of high quality (Level 1b), the lack of further studies on the model limit its LoR. The Tube 3 module on the dV-Trainer also simulates UVA and has demonstrated face, content and construct B validity amongst 20 participants [32]. Kim et al. [33] recruited 11 novices and trained them using this module over seven sessions. The participants then performed UVA on synthetic materials and, later, on a UVA model, thereby demonstrating a level of concurrent and predictive validities.

Two studies were identified, describing models used in full procedural simulation for RARP. A chicken genitourinary model was developed and used to perform a full RARP and demonstrated face, content and construct B validity amongst 20 participants [34]. The European Association of Urology (EAU) Robotic Urologic Section (ERUS) has designed and developed a structured training program and curriculum in urology focusing on RARP. The simulation component of the curriculum includes training on VR, dry-lab, animal and cadaveric models. Volpe et al. [35] established the face validity of the ERUS Curriculum amongst ten robotic fellows. Currently, the curriculum has a LoR of 4.

Open Urological Surgery

Six studies were identified describing training models for 15 open urological procedures (Table 5). The majority of the procedures were performed on FFCs, conducted as part of the BAUS training programme [12]. The authors demonstrated face and content validity of FFCs for common and emergency urological operations, amongst 75 residents and 27 experts. This study was awarded a LoE of 4. Similarly, Cabello et al. [36] demonstrated the use of thiel-embalmed cadavers in Renal transplantation and demonstrated face validity amongst 28 subjects. Several bench models were also described and validated for suprapubic catheterisation (SPC; n=3) and vasovasostomy (n=1). Of these, the Uro-Emerge SPC model and the silicone tube and rat vas deferens vasovasostomy models both demonstrated construct A and predictive validities, achieving a LoE of 2c and LoR of 4. Due to the nature of the studies and lack of supportive data, it was not possible to make recommendations for the remaining models in this section.

Non-technical Skills

Two individual concepts were identified for integrated non-technical skills training in urology, both of which received a LoR of 2. First is full immersion simulation (Imperial College, London, UK), a low-fidelity 360^{o} inflatable operating environment. Brunckhorst et al. [14] conducted a RCT where the randomised arm received ureteroscopy and non-technical skills training through a validated curriculum and assessed both arms. The randomised group outperformed the control arm in all aspects including non-technical skills, thereby demonstrating construct A validity. Furthermore, the authors confirmed a strong correlation between technical and non-technical skills [37]. Brewin et al. [38] also used full immersion simulation for TURP and non-technical skills and demonstrated face, content and construct B validity, with a Kirkpatrick Level 1 Evidence for educational impact. Full immersion simulation received.

Two studies [39 40] utilised high fidelity simulation within a simulated laparoscopic Operating Room (OR; Storz, Tuttlingen, Germany) using a high-fidelity SimMan3G mannequin (Laerdal, Wappingers Falls, NY) and Partial nephrectomy renal model (Table 3). The authors executed a partial nephrectomy scenario with complications. High-fidelity OR team training demonstrated face (n=2), content (n=2) and construct B validation in both technical skills (n=2) and non-technical skills (n=1).

DISCUSSION

Surgical simulation has seen an exponential growth in the last couple of decades, with increasing number of new models being developed and validated. This study has demonstrated that simulation-based urological training has made considerable progress. High numbers of procedure-specific models have been developed for endourology and also a select few for laparoscopic and robot-assisted urology, which previously concentrated on generic skills acquisition [41]. Four Level 1b studies were identified in endourology [10 11 15 42] and two in robot-assisted urology [31 43]. In contrast, open urological surgery has had a limited number of simulator production and subsequent validation, which may owe to the nature of the surgery, making it difficult to replicate.

Based on the currently available data, simulation-based urological training should be adopted by healthcare organisations, through utilisation of validated models. Efforts should be made to identify the best aspects of each training model and procedure-specific simulation curricula should be developed and validated, employing different modalities. Several generic skills curricula have been reported in the literature including the validated Fundamentals of Laparoscopic Surgery (FLS©) skills curriculum, which was adapted into the urology-specific Basic Laparoscopic Urologic Surgery (BLUS©) skills curriculum by Sweet et al.[44]. A similar curriculum has been designed for robot-assisted surgery, entitled Fundamentals of Robotic Surgery (FRS©) [45], and is currently undergoing validation.

Furthermore, a number of procedure-specific curricula have also been described and validated. In robotic surgery, the European Association of Urology (EAU) Section of Robotics

(ERUS) have developed a 12-week training curriculum for RARP [35]. It includes e-learning, one week of structured multi-modality simulation training and supervised modular training. Eight training surgeons took part in the programme and the authors demonstrated face validity, feasibility, acceptability and educational impact. In endourology, the curricula employed by Soria et al. [16] and Brunckhorst et al. [14] constitute important examples.

Team training is an important concept, which has been fairly neglected in the literature. The concepts of full immersion simulation and using high-fidelity simulated ORs can be important means to provide both technical and non-technical skills training for all members of the surgical team. The former modality is especially important, as it is significantly cheaper than the latter. Team training is especially important in robot-assisted surgery as the surgeon is at the console away from the patient and, thus, relies on assistants for the safety of the patient. The Xperience® Team Trainer (XTT; Mimic Technologies) is developed to train both the surgeon and the assistant. Although it is currently used alongside generic skills modules, it is hoped that procedure-specific modules will also be developed. The platform has demonstrated face, content, construct and concurrent validity [46].

A significant boundary for adoption of simulation training is cost effectiveness of the platforms. A significant proportion of the listed tools are commercially available, save a select few, which are experimental models, developed by institutions. Hence, they are usually high-fidelity models and a significant cost attached to each. The number of validated low-fidelity and inexpensive models are limited. However, where affordable, institutions are strongly recommended to invest in models with evidence-base, as presented.

This article, as with all reviews, has a few limitations. Firstly, despite every effort, relevant studies may have been missed. Although RCTs demonstrate the highest LoE, only a handful of these were identified in the literature. There are no Level 1a studies and the conducted RCTs are all small-scale Level 1b studies. Furthermore, earlier simulators have higher LoE and LoR as more studies have been conducted using them. In contrast, newly developed simulators have not had as thorough evaluation and hold lower LoR. Consequently, it is important that greater emphasis is made on validating the more recently developed simulators.

Very few studies compared the available models to assess strengths and weaknesses of each model. Most studies demonstrate face and content validity, which are subjective measures of validation as opposed to more objective measures including construct, concurrent and predictive validity. Moreover, there is no clear consensus on the exact definitions of validity terms. In the included studies, the use of these terms varied and, therefore, were judged based on the definitions in Figure 2. Another limitation on quality of studies was that majority of studies recruited medical students, possibly due to availability.

Standardisation of validation is an important factor for future studies. It is strongly recommended that authors conform to the definitions of validity terms by McDougall [5] and van Nortwick et al. [6] (Figure 2). As per these definitions, content validity should be limited to experts only. Furthermore, studies should mainly recruit residents in-training, as they will ultimately be the first to receive such training. Furthermore, with urology having produced an outstanding number of validation studies, these should be utilised for power calculations prior to studies. Expert(s) are recommended to pilot and explore each tool and a Delphi technique should be utilised to decide which tasks should be investigated and utilised prior to investigation. The concept of "distributed" training, with a maximum of two sessions performed per day, at least one hour apart has also been recommended in the literature [47]. Finally, authors should discuss the value of their study in light of the modified educational OCEBM classification system for LoE and LoR, as adapted by the European Association of Endoscopic Surgery [7].

CONCLUSION

With the various changes in surgical training, simulators have become of increasing interest in all surgical specialties. It is of utmost importance to identify which of these models would be most valuable to be implemented in a curriculum for postgraduate training programs. Across the field of urology, there has been a significant increase in the number of simulators developed. However, there are still too few a number of validation studies with high level of evidence. Nevertheless, efforts should be made to utilise the currently available models in a curricular approach.

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Conflict of Interest

None declared

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FIGURE LEGENDS

Figure 1: Study selection process, according to the Preferred Reporting Items for Systematic reviews And meta-analysis (PRISMA) statement

Figure 2: Definitions of Validity, based on definitions by McDougall et al. [5] and van Nortwick et al. [6]. Abbreviation: OSATS – Objective Structured Assessment of Technical Skills

TABLES

Table 1: Validation studies on urological training models (1990–2015) for Urethrocystoscopy (UCS), Ureterorenoscopy (URS) and Percutaneous access and/or nephrolithotomy (PCNL). Abbreviations: LoE- Level of Evidence, LoR- Level of Recommendation, VR- virtual reality.
*models also used to perform intravesical botolinum toxin injections, •model also used for bladder biopsy

Procedure	Name of Model	Institution / Manufacturer	Type of Model	Study	Validation	Participants		LoE	LoR
						n	Demographics		
UCS	ETXY-Uro Adam	ProDelphus, Olinda – PE, Brazil	Bench	Soria et al. (2014)	Face, Content, Construct B	50	40 Trainees, 10 Experts	2b	3
	URO-Trainer	Karl Storz GmbH, Tuttlingen, Germany	VR	Reich et al. (2006)	Content, Construct A, Construct B	36	24 Medical Students, 12 Residents	2b	3
	URO Mentor	Simbionix, Lod, Israel	VR	Wilhelm et al. (2002)	Construct A, Construct B	21	Medical Students	2a	1
				Shah et al. (2002)	Construct A	14	Urology Nurses	2c	
				Shah et al. (2002)	Construct A, Construct B	17	10 Novices, 7 Experts	2b	
				Gettman et al. (2008)	Face, Construct B	57	30 Novices, 27 Experts	2b	
				Gettman et al. (2009)	Face, Construct A	10	Novices	2c	
				Dolmans et al. (2009)	Face, Content	89	33 Referent, 56 Experts	4	
				Schout et al. (2010a)	Construct B	100	100 Interns	1b	
				Schout et al. (2010b)	Construct B	80	50 Novices, 30 Experts	2b	
				Persoon et al. (2011)	Construct A	86	Medical Students	1b	
				Shamim Khan et al. (2013)	Face, Content, Construct B	33	33 Trainees	2b	
				Zhang et al. (2013)	Construct A	18	Urologists	2c	
	URO Mentor + Glass globe	Catharina Hospital Eindhoven, Eindhoven, Netherlands	VR + Bench	Persoon et al. (2010)	Face, Construct B	32	Medical Students	2a	3
	URO Mentor + Uro Scopic Trainer	Simbionix, Lod, Israel + Limbs and Things, Bristol, UK	VR + Bench	Matsumoto et al. (2006a)	Face, Construct B	16	Residents	2c	3

	Boar Urinary tract	Department of Urology, Mayo Clinic, Arizona, Phoenix, AZ	Animal•	Grimsby et al. (2011)	Construct A	2	Residents	2c	4
	Live Porcine	Minimally Invasive Surgery Centre Jesús Usón Cáceres, Spain	Animal	Soria et al. (2014)	Face, Content	50	40 Trainees, 10 Experts	2b	3
	Fresh Frozen Cadaver	University of Alabama at Birmingham, Birmingham, Alabama	Cadaver	Bowling et al. (2010)	Construct B	29	Obstetric Residents	1b	2
		British Association of Urological Surgeons, UK	Cadaver•*	Ahmed et al. (2015)	Face, Content	102	75 Participants (Trainees, Specialists), 27 Experts	4	
URS	Penrose drain	University of Toronto, Canada	Bench	Matsumoto et al. (2002)	Construct A	40	Medical Students	1b	2
	Scope Trainer	Mediskills, Northampton, UK	Bench	Brehmer et al. (2002)	Face, Content, Construct B	14	5 Trainees, 9 Consultants	2b	3
				Brehmer et al. (2005)	Construct A	26	26 Residents	2c	
	Adult Ureteroscopy Trainer	Ideal Anatomic Modelling, Holt, Michigan, USA	Bench	White et al. (2010)	Face, Content, Construct B	46	Medical Students, Residents, Representatives	2b	3
	Endo-Urologie Modell	Karl Storz GmbH, Tuttlingen, Germany	Bench	Mishra et al. (2011)	Face, Construct A	21	Urologists	2b	3
	Cook URS Model	Cook Medical, Bloomington, IN, USA	Bench	Blankstein et al. (2015)	Face, Content, Construct A	15	Junior Residents	2c	3
	Uro Scopic Trainer	Limbs and Things, Bristol, UK	Bench	Matsumoto et al. (2002)	Construct A	40	Medical Students	1b	2
				Matsumoto et al. (2001)	Construct A, Construct B	17	Residents	2c	
				Mishra et al. (2011)	Face, Construct A	21	Urologists	2b	
			Bench + Porcine	Chou et al. (2006)	Concurrent	16	Medical Students	2a	
	ETXY-Uro Adam + Porcine renoureteral tissue + Live Porcine	Minimally Invasive Surgery Centre Jesús Usón Cáceres, Spain	Bench + Animal	Soria et al. (2014)	Face, Content, Construct A, Construct B	50	40 Trainees, 10 Experts	2b	3
	URO Mentor	Simbionix, Lod, Israel	VR	Wilhelm et al. (2002)	Construct A, Construct B	21	Medical Students	2a	2

				Michel et al. (2002)	Face, Content	-	Urologists	4	
				Watterson et al. (2002)	Face, Construct A	20	Novices	2a	
				Jacomides et al. (2004)	Construct A, Construct B	32	16 Students, 16 Residents	2b	
				Knoll et al. (2005)	Construct B	20	Urologists	2c	
				Dolmans et al. (2009)	Face, Content	52	20 Referents, 32 Experts		
				Mishra et al. (2011)	Face, Construct A	21	Urologists	2b	
				Cai et al. (2013)	Construct A	30	17 Attending physicians, 13 Associate Chief Physicians	2c	
			VR + Porcine	Chou et al. (2006)	Concurrent	16	Medical Students	2a	
			VR + Cadaver	Ogan et al. (2004)	Construct B, Predictive	32	16 Students, 16 residents	2b	
				Matsumoto et al. (2006a)	Predictive	16	16 Medical Students	2c	
	URO Mentor + Uro Scopic Trainer	Simbionix, Lod, Israel + Limbs & Things Ltd, Bristol, UK	VR + Bench	Matsumoto et al. (2006b)	Face, Construct B	16	Residents	2b	2
				Brunckhorst et al. (2015)	Face, Construct B	32	Medical Students	2a	
	Fresh Frozen Cadavers	British Association of Urological Surgeons, UK	Cadaver	Ahmed et al. (2015)	Face, Content	102	75 Participants, 27 Experts	4	N/A
PCNL	C-arm Trainer (CAT)	SimPORTAL, University of Minnesota, MN, USA	Bench	Veneziano et al. (2015)	Face, Content	14	Urologists	4	N/A
	PERC Mentor	Simbionix, Lod, Israel	VR	Knudsen et al. (2006)	Construct A	63	31 Medical Students, 31 Residents, 1 Fellow	2a	2
				Papatsoris et al. (2012)	Construct A	36	Trainees	2c	
				Shamim Khan et al. (2013)	Face, Content, Construct B	33	33 Trainees	2b	
			VR + Animal	Mishra et al. (2010a)	Face, Content, Construct B, Predictive	24	15 Novices, 9 Experts	2b	
				Mishra et al. (2010b)	Content	24	Experts	4	

	Porcine kidney model	Xuanwu Hospital of Capital Medical University and Peking University, China	Animal	Zhang et al. (2008)	Face	42	Urologists	4	N/A
	Porcine kidney in chicken carcass model	Southern Illinois University School of Medicine, Springfield, IL, USA	Animal	Hammond et al. (2004)	Face	-	Residents	4	N/A

Table 2: Validation studies on urological training models (1990–2015) for Transurethral resection and laser prostate therapies. Abbreviations: LoE- Level of Evidence, LoR- Level of Recommendation, TURP - Transurethral resection of the prostate, VR- virtual reality, TURBT - Transurethral resection of bladder tumours, HoLEP - Holmium laser enucleation of the prostate, PVP - Photoselective vaporisation of the prostate, VR- virtual reality.

Procedure	Model	Institution / Manufacturer	Type of Model	Study	Validation	Participants		LoE	LoR
						n	Demographics		
TURP	Bristol TURP Trainer	Limbs & Things Ltd, Bristol, UK	Bench	Shamim Khan et al. (2013)	Face, Content, Construct B	33	33 Trainees	2b	2
				Brewin et al. (2014)	Face, Content, Construct B	16	8 Novices, 8 Experts	2b	
				Brewin et al. (2015)	Face, Content, Construct B	20	10 Trainees, 10 Experts	2b	
	SurgicalSIM TURP (UW TURP Trainer)	METI, Seattle, WA, USA	VR	Sweet et al. (2004)	Face, Content, Construct B	91	19 Novices, 72 Certified Urologists	2b	2
				Rashid et al. (2007)	Construct B	136	72 Urologists, 45 Residents, 19 Novices	2b	
				Hudak et al. (2010)	Construct B	35	4 Medical Students, 19 Trainees, 12 Residents	2b	
	TURP Simulator	University College London, UK	VR	Ballaro et al. (1999)	Content	3	3 Urologist	4	N/A
	UroSim/TURPSim	VirtaMed AG, Zurich, Switzerland	VR	Bright et al. (2012)	Content, Construct B	18	11 Novices, 7 Experts	2b	2
				Zhu et al. (2013)	Face, Construct A	38	Urology Trainees	2a	
				Kishore et al. (2009)	Construct A	18	Medical Students	2a	
	PelvicVision	Melerit Medical AB, Linkoping, Sweden	VR	Kallstrom et al. (2005)	Content, Construct A	44	37 Urologist, 7 Students	2c	3
			VR	Kallstrom et al. (2010a)	Construct A	24	Urologists	2c	
				Kallstrom et al. (2010b)	Face, Content, Construct B	20	11 Medical Students, 9 Urologists	2b	
	Uro Trainer	Karl Storz GmbH, Tuttlingen, Germany	VR	Schout et al. (2009)	~~Face, Content~~	97	20 Experts, 77 Novices	4	4
				Mishra et al. (2010c)	Face, Content	19	10 Experts, 9 Novices	4	
	Fresh Frozen Cadavers	British Association of Urological Surgeons, UK	Cadaver	Ahmed et al. (2015)	Face, Content	102	75 Participants, 27 Experts	4	N/A
TURBT	Bristol TURBT Model	Limbs & Things Ltd, Bristol, UK	Bench	Shamim Khan et al. (2013)	Face, Content, Construct B	33	33 Trainees	2b	3
	Simbla TURBT Simulator	SAMED GmbH, Dresden, Germany	Bench	de Vries et al. (2015)	Face, Content, Construct B	76	25 Novices, 26 Intermediates, 25	2b	3

							Experts		
	URO-Trainer	Karl Storz GmbH, Tuttlingen, Germany	VR	Reich et al. (2006)	Content, Construct A, Construct B	36	24 Medical Students, 12 Residents	2b	3
				Schout et al. (2009)	~~Face, Content~~	64	19 Experts, 45 Novices	4	
				Kruck et al. (2011)	Construct A	15	Residents		
HoLEP	Holmium Surgical Simulator	Kansai Medical University, Japan	Bench	Aydin et al. (2014)	Face, Content	36	13 Urology Trainees, 23 Senior Urologists	4	N/A
	UroSim	VirtaMed AG, Zurich, Switzerland	VR	Kuronen-Stewart et al. (2015)	Face, Content, Construct B	42	6 Experts, 18 Trainees, 18 Novices	2b	3
PVP	GreenLight Simulator	American Medical Systems Inc, Minnetonka, MN, USA	VR	Herlemann et al. (2013)	Face, Construct B	18	9 Novices, 9 Advanced users	2b	2
				Aydin et al. (2015)	Face, Content, Construct A, Construct B	46	25 Novices, 14 Intermediates, 7 Experts	2b	
				Noureldin et al. (2014)	Construct A, Construct B	25	25 Trainees	2b	
Diode PVP	MyoSim	VirtMed AG, Zurich, Switzerland	VR	Angulo et al. (2014)	Construct B	18	Medical students, residents, specialists	2b	3

Table 3: Validation studies on urological training models (1990–2015) for Laparoscopic Urology. Abbreviations: UVA- urethro-vesical anastomosis, LoE- Level of Evidence, LoR- Level of Recommendation, VR- virtual reality.

Procedure	Model	Institution / Manufacturer	Type of Model	Study	Validation	Participants n	Participants Demographics	LoE	LoR
Partial/Radical Nephrectomy	Procedicus MIST Nephrectomy Simulator	Mentice, Gothenburg, Sweden	VR	Brewin et al. (2010)	Face, Content, Construct B	28	8 Experts, 10 Novices, 10 Trainees	2b	2
				Shamim Khan et al. (2013)	Face, Content, Construct B	33	33 Trainees	2b	
				Wijn et al. (2010)	~~Construct B~~	64	22 Novices, 32 Intermediates, 10 Experienced	2b	
	Partial Nephrectomy Renal Model	University of California Irvine Medical Center, California, USA	Bench	Fernandez et al. (2012)	Face, Content	5	5 Urology Fellows	4	2
				Lee et al. (2012)	Construct B	8	8 Residents	2b	
				Abdelshehid et al. (2013)	Construct B	18	9 Residents	2b	
	Rabbit model	University Hospital Gasthuisberg, Belgium	Animal	Molinas et al. (2004)	Construct B	20	10 Medical Students, 10 Gynaecologists	2b	3
	Porcine Kidney		Animal	De Win et al. (2013)	Content, Construct A, Predictive	22	Medical Students	2b	3
Pyeloplasty	Pyeloplasty Simulator Model	University of Minnesota, Minnesota, USA	Bench	Poniatowski et al. (2014)	Face, Content, Construct B	31	Clinical Urologists	2b	3
	3D Silicon Model	The Hospital for Sick Children, Toronto, Ontario, Canada	Bench	Cheung et al. (2014)	Face, Content	27	24 Paediatric Urology Fellows, 3 Faculty Members	4	N/A
	Porcine Bladder	Department of Urology, SLK Klinikum Heilbronn, Germany	Animal	Teber et al. (2010)	Construct A	5	5 Laparoscopic Surgeons	3	4
	Chicken crop model	Sun Yat-sen Memorial Hospital, Sun Yat-sen University, Guangzhou, Guangdong, China	Animal	Jiang et al. (2013)	Construct B	15	5 Experts, 5 Specialists, 5 Junior Residents	2b	3
Ureteral Re-implantation	Hydrogel model	Cleveland Clinic, Cleveland, OH, USA	Bench	Tunitsky et al. (2013)	Face, Content, Construct B	20	12 Trainees, 5 Robotic Experts, 4 Procedure Experts	2b	3

UVA	Latex UV Model (UVM)	McMaster University, Hamilton, Ontario, Canada	Bench	Sabbagh et al. (2012)	Face, Predictive	28	Senior Residents, Fellows, Staff Surgeons	2a	3
	Live Porcine	McMaster University, Hamilton, Ontario, Canada	Animal	Sabbagh et al. (2012)	Face	28	Senior Residents, Fellows, Staff Surgeons	2a	3
	Porcine Intestine	Baylor College of Medicine, Houston, Texas, USA	Animal	Boon et al. (2008)	Construct B	12	Residents, Medical Students	2b	3
	Chicken Chest Model	AMC University Hospital, Amsterdam, Netherlands	Animal	Laguna et al. (2006)	Construct B	5	Urologists	2c	4

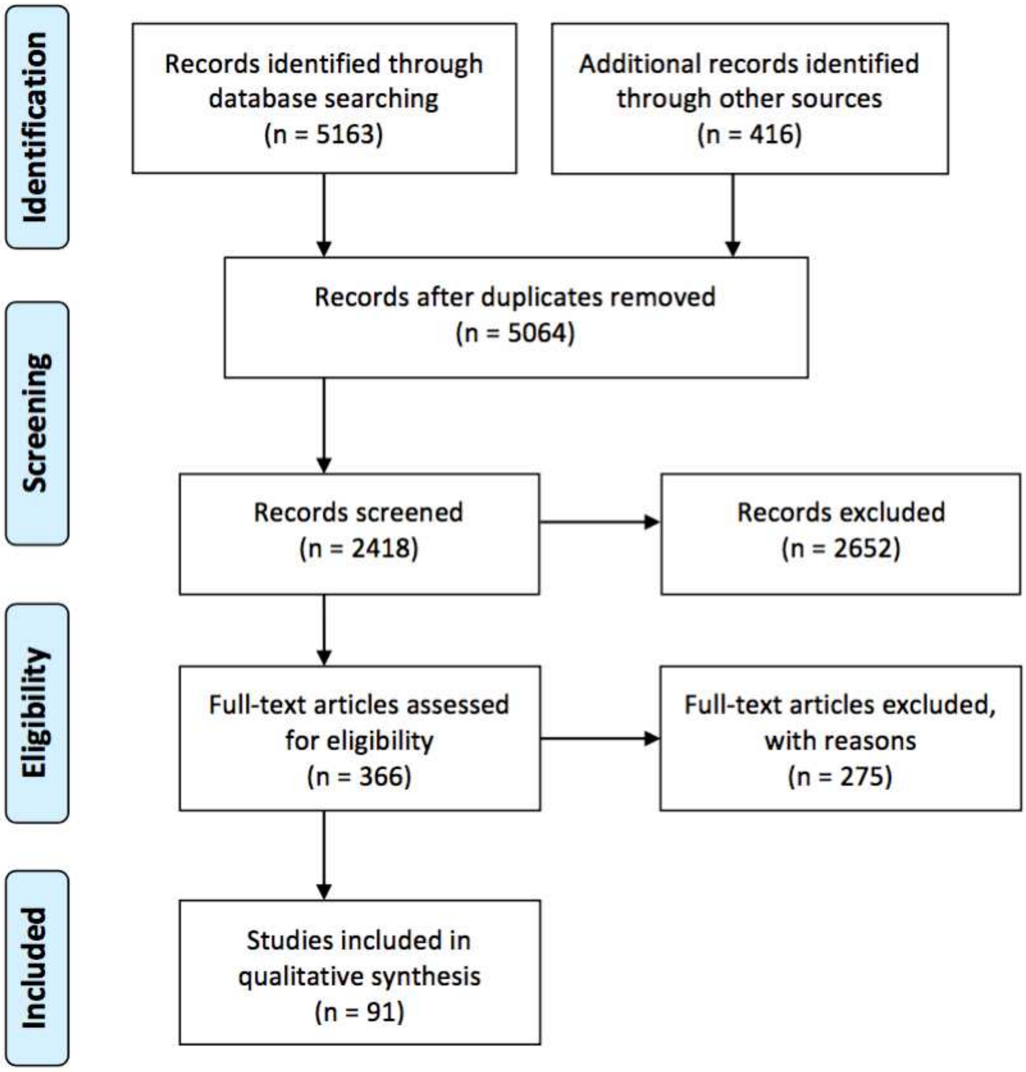
Table 4: Validation studies on urological training models (1990–2015) for Robot-assisted Urological Surgery. Abbreviations: LoE- Level of Evidence, LoR- Level of Recommendation, RAPN- robot-assisted partial nephrectomy, UVA- urethro-vesical anastomosis, RARP- robot-assisted radical prostatectomy, VR- virtual reality, HoST- Hands-on Surgical Training, RoSS- Robotic Surgical Simulator, GU- genitourinary, ERUS- EAU Robotic Urology section.

Procedure	Model	Institution / Manufacturer	Type of Model	Study	Validation	Participants		LoE	LoR
						n	Demographics		
RAPN	Porcine kidney + Styrofoam ball	USC Institute of Urology, University of Southern California, Los Angeles, CA, USA	Animal	Hung et al. (2012a)	Face, Content, Construct B	46	24 Novices, 9 Intermediates, 13 Experts	2b	2
			+ Cadaver	Hung et al. (2012b)	Concurrent, Predictive	24	2 Students, 1 Urology Intern, 14 Residents, 5 Fellows, 2 Urology staff	1b	
	dV-Trainer	Mimic Technologies Inc., Seattle, WA, USA	AR + VR + Animal	Hung et al. (2015)	Face, Content, Construct B, Concurrent	42	15 novices, 13 intermediates, 14 experts	2b	3
UVA	HoST/RoSS	Simulated Surgical Systems; Williamsville, NY, USA	AR + VR	Chowriappa et al. (2015)	Face, Concurrent	52	30 Fellows, 22 Residents	1b	3
	Tube 3/dV-Trainer	Mimic Technologies, Inc., Seattle, WA, USA	VR	Kang et al. (2014)	Face, Content, Construct B	20	10 Novices, 10 Experienced Surgeons	2b	3
				Kim et al. (2015)	Concurrent, Predictive	11	8 Residents, 3 Fellows	2c	
RARP	Porcine GU Model	University of Southern California, Los Angeles, CA, USA	Animal	Alemozaffar et al. (2014)	Face, Content, Construct B	20	10 Novices, 10 Experts	2c	4
	ERUS Curriculum	European Association of Urology	VR + Bench + Animal + Cadaver	Volpe et al. (2014)	Face	12	10 Experts, 2 Fellows	2c	4

Table 5: Validation studies of urological training models for Open Urological Surgery (1990–2015). Abbreviations: LoE- Level of Evidence, SPC- Suprapubic Catheterisation.

Procedure	Model	Institution / Manufacturer	Type of Model	Study	Validation	Participants		LoE
						n	Demographics	
Suprapubic Catheterisation	SPC Training model	Centre for Education in Medicine, Northwestern University Feinberg School of Medicine, Chicago, IL	Bench	Singal et al. (2015)	Face, Content	25	25 General Surgeons	4
	SPC Training model	Western Hospital, Melbourne, Australia	Bench	Hossack et al. (2013)	Face	30	30 Trainees	4
	UroEmerge SPC model	St Bartholomew's and The Royal London Hospitals, London, UK	Bench	Shergill et al. (2008)	Construct A, Predictive	36	36 Junior Trainees	2c
Circumcision	Fresh Frozen Cadaver	British Association of Urological Surgeons, UK	Cadaver	Ahmed et al. (2015)	Face, Content	102	75 Participants (Trainees, Specialists), 27 Experts	4
Vasectomy	Fresh Frozen Cadaver	British Association of Urological Surgeons, UK	Cadaver	Ahmed et al. (2015)	Face, Content	102	75 Participants, 27 Experts	4
Vasovasostomy	Silicone tube + Rat vas deferens	University of Toronto, Ontario, Canada	Bench + Animal	Grober et al. (2004)	Construct A, Predictive	13	Residents	2c
Testicular Fixation	Fresh Frozen Cadaver	British Association of Urological Surgeons, UK	Cadaver	Ahmed et al. (2015)	Face, Content	102	75 Participants, 27 Experts	4
Hydrocele Repair	Fresh Frozen Cadaver	British Association of Urological Surgeons, UK	Cadaver	Ahmed et al. (2015)	Face, Content	102	75 Participants, 27 Experts	4
Radical Orchidectomy	Fresh Frozen Cadaver	British Association of Urological Surgeons, UK	Cadaver	Ahmed et al. (2015)	Face, Content	102	75 Participants, 27 Experts	4
Open Cystostomy	Fresh Frozen Cadaver	British Association of Urological Surgeons, UK	Cadaver	Ahmed et al. (2015)	Face, Content	102	75 Participants, 27 Experts	4
Management of Bladder Perforation	Fresh Frozen Cadaver	British Association of Urological Surgeons, UK	Cadaver	Ahmed et al. (2015)	Face, Content	102	75 Participants, 27 Experts	4
Transureteroureterostomy	Fresh Frozen Cadaver	British Association of Urological Surgeons, UK	Cadaver	Ahmed et al. (2015)	Face, Content	102	75 Participants, 27 Experts	4

Boari Flap / Psoas Hitch	Fresh Frozen Cadaver	British Association of Urological Surgeons, UK	Cadaver	Ahmed et al. (2015)	Face, Content	102	75 Participants, 27 Experts	4
Open Surgical Packing of Pelvis	Fresh Frozen Cadaver	British Association of Urological Surgeons, UK	Cadaver	Ahmed et al. (2015)	Face, Content	102	75 Participants, 27 Experts	4
Nephrectomy	Fresh Frozen Cadaver	British Association of Urological Surgeons, UK	Cadaver	Ahmed et al. (2015)	Face, Content	102	75 Participants, 27 Experts	4
Renal Graft Transplant	Thiel-Embalmed Cadaver	Universidad Autonoma de Madrid, Madrid, Spain	Cadaver	Cabello et al. (2014)	Face	28	Residents, Junior Transplant Surgeons	4


Identification
Screening
Eligibility
Included
Records identified through database searching (n = 5163)
Additional records identified through other sources (n = 416)
Records after duplicates removed (n = 5064)
Records screened (n = 2418)
Records excluded (n = 2652)
Full-text articles assessed for eligibility (n = 366)
Full-text articles excluded, with reasons (n = 275)
Studies included in qualitative synthesis (n = 91)

Face Validity – Opinions, including of non-experts, regarding the realism of the simulator

Content Validity – Opinions of experts about the simulator and its appropriateness for training

Construct Validity

- **A** – one group – Ability of the simulator to assess and differentiate between the level of experience of an individual or group measured over time
- **B** – between groups – Ability of the simulator to distinguish between different levels of experience

Concurrent Validity – Comparison of the new model against the older and gold standard, usually by OSATS

Predictive Validity – Correlation of performance with operating room performance, usually measured by OSATS

LoE – Level of Evidence
LoR – Level of Recommendation
RCT – Randomised Contrroled Trial
VR – Virtual Reality
FFC – Fresh Frozen Cadaver
TURP – transurethral resection of the prostate
TURBT – transurethral resection of bladder tumours
UVA – urethro-vesical anastomosis
RARP – robot-assisted radical prostatectomy

ALL INCLUDED STUDIES

ABDELSHEHID, C. S., QUACH, S., NELSON, C., GRAVERSEN, J., LUSCH, A., ZARRAGA, J., ALIPANAH, R., LANDMAN, J. & MCDOUGALL, E. M. 2013. High-fidelity simulation-based team training in urology: evaluation of technical and nontechnical skills of urology residents during laparoscopic partial nephrectomy. *J Surg Educ,* 70**,** 588-95.

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SUPPLEMENTARY TABLES

Table 1: Modified Levels of evidence classification for validation studies, adapted from Oxford Centre for Evidence-Based Medicine classification by the European Association of Endoscopic Surgeons (Carter et al., 2005).

Level of Evidence	Criteria
1a	Systematic reviews (meta-analysis) containing at least some trial of level 1b evidence, in which results of separate, independently controlled trials are consistent
1b	Randomised controlled trial of good quality and of adequate sample size (power calculations)
2a	Randomised trials of reasonable quality and/or of inadequate sample size
2b	Nonrandomised trials, comparative research (parallel cohort)
2c	Nonrandomised trials, comparative research (historical cohort, literature controls)
3	Nonrandomised, non-comparative trials, descriptive research
4	Expert opinions, including the opinion of Work Group members

Table 2: Levels of recommendation for training models, adapted from Oxford Centre for Evidence-Based Medicine classification by the European Association of Endoscopic Surgeons (Carter et al., 2005).

Level of Recommendation	Criteria
1	Based on one systematic review (1a) or at least two independently conducted research projects classified as 1b
2	Based on at least two independently conducted research projects classified as level 2a or 2b, within concordance
3	Based on one independently conducted research project level 2b, or at least two trials of level 3, within concordance
4	Based on one trial at level 3 or multiple expert opinions, including the opinions of Work Group members (e.g. level 4)

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